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SILICON IMPROVED SCHOTTKY BARRIER DIODE

BACKGROUND OF THE INVENTION

The present invention relates to a silicon improved Schottky barrier diode, particularly to a Schottky barrier diode of high - voltage with a Multi Drain (MD) technology.

Schottky barrier diodes (generally indicated as SBD) are used as voltage rectifiers in many power switching applications. In fact whenever a current is switched to an inductive load, such as an electric motor, high - voltage transients on the conductive lines are induced.

Usually to suppress these transients, that is to rectify a waveform, a PN junction diode is used, and said PN diode is placed across each switching means, for example a power transistor, to clamp the voltage excursions.

PN junction diodes can be used for this application, but they store minority carriers when forward biased, and the extraction of these carriers generates a reverse current having a large transient during switching.

In switching applications, the PN diode is turned on and off by fast pulses, and the reverse recovery finite time limits the rate of pulses that can be applied, thus limiting the diode switching speed.

To overcome these drawbacks a metal - semiconductor rectifying junction, called MSJ, is used.

In this type of device,the forward current consists of majority carriers injected from the semiconductor into the metal.

Consequently, MSJs do not store minority carriers when forward biased, and the reverse current transient is negligible. This means that

the MSJ can be turned off faster than a PN diode, and therefore they dissipate a negligible power during switching.

However the on - resistance of the MSJ increases sharply with the growth of the voltage, and this occurrence limits their use to a voltage range of about 150 V - 200 V.

In ultra fast switching applications, over 200 V, mainly a bipolar diode is used. This diode is responsible for an important part of the dissipated power due mainly to the drain epitaxial layer resistance, and the dissipated power depends, also, on the doping concentration of the epitaxial layer itself.

In fact the power dissipation occurs in this type of diode during the conduction phase. If the working frequency increases, the power dissipation occurs more and more during the off - commutation. Power dissipation occurs not only in the diode, but also in a parasitic MOS transistor due to the diode charge recovery phenomenon.

In view of the state of the art described, it is an object of the present invention to provide a device able to suppress voltage transients, to work at high - voltage and to limit power dissipation.

It is another object of the present invention to propose an alternative device to bipolar diodes in ultra fast switching applications.

SUMMARY OF THE INVENTION

According to the present invention, such objects are achieved by a Schottky barrier diode comprising a substrate region of a first conductivity type formed in a semiconductor material layer of the same conductivity type and a metal layer, characterized in that at least a doped region of a second conductive type is formed in said semiconductor material layer, each one of said doped regions being disposed under said metal layer and being separated from other doped regions by portions of said

semiconductor material layer. According to the present invention it is possible to make a Schottky barrier diode having an higher voltage breakdown. Moreover, according to the present invention it is possible to make a Schottky barrier diode having a lower on - resistance with respect to the prior art.

BRIEF DESCRIPTION OF THE DRAWINGS

The features and the advantages of the present invention will be made evident by the following detailed description of an embodiment thereof, which is illustrated as a non-limiting example in the annexed drawings, wherein:

Figure 1 shows a schematic cross sectional view of a Schottky barrier diode according to the prior art;

Figure 1A shows the relationship between the breakdown voltage and the on - resistance according to the prior art;

Figure 2 shows a first embodiment of a Multi Drain Schottky barrier diode according to the present invention;

Figure 3 shows a second embodiment of a Multi Drain Schottky barrier diode according to the present invention;

Figure 4A shows another schematic cross sectional view of the Schottky barrier diode according to the prior art;

Figure 4 shows a top plan view of the first embodiment of Figure 2;

Figure 5 shows a cross sectional view of the first embodiment of Figure 2 along the line V - V.

DETAILED DESCRIPTION

In Figure 1 a schematic cross sectional view of a Schottky barrier diode according to the prior art is shown. This device, indicated as 1,

employs an n - type epitaxial layer 2 on an n^+ - type substrate 3, to reduce the diode series resistance.

The resistivity values and the thickness of a device adapted to sustain a voltage in a range between 100 V and 500 Vmust be in a range of resistivity between 5 Ohm * cm and 20 Ohm * cm and in a range of thickness between 15 μm and 50 μm.

Diode 1 is fabricated by depositing a metal layer 4 of suitable size onto the n - type epitaxial layer 2, and by producing a metal - semiconductor contact 5, called an ohmic contact. Said ohmic contact has a resistance negligibly small compared with the resistance of the n^+ - type substrate 3 to which the ohmic contact itself is applied.

The metal layer 4 represents a first electrode 6, called the anode, and the ohmic contact 5 represents a second electrode 7, called the cathode.

Device 1 has a large leakage reverse current and it has a low breakdown voltage because of the concentration of the electric field near the periphery of the device.

Moreover, the on - resistance of diode 1 increases sharply with the growth of the voltage, and this occurrence limits its use to a range of voltage between 150 V - 200 V.

In fact the law that links the voltage breakdown with the epitaxial layer resistivity is: $BV \propto \rho^{3/4}$, where BV is the breakdown voltage and ρ is the epitaxial layer resistivity.

Such a formula is shown in the graph of Figure 1A, wherein there is an abscissa axis illustrating the breakdown voltage expressed in V and an ordinate axis illustrating the on - resistance of the active area expressed in mOhm * cm^2.

To overcome these problems a Schottky barrier diode with a low on -

resistance and a high breakdown voltage with drain layers comprising a Multi Drain structures, according to the present invention, as shown in Figure 2.

In this way a device having a higher voltage capability for a given epitaxy doping level, a higher voltage breakdown and a lower on - resistance with respect to known devices is realized.

In Figure 2 a cross sectional view of a first embodiment of a Multi Drain Schottky barrier diode according to the present invention is shown.

As shown in Figure 2, the new device 8 comprises a heavily doped substrate 9 onto which a semiconductor layer 10 is formed, for example by epitaxial growth. In a specific embodiment, either substrate 9 and/or semiconductor layer 10 are of n type conductivity.

On substrate 9 an ohmic contact (not shown) is formed by creating a thin, heavily doped semiconductor region of the same conductivity type placed between the metal (not shown) and substrate 9.

Over the surface of semiconductor layer 10, also called an epitaxial layer, a thin silicide layer 11 is formed, for example by thermal growth, made by, for example, PtNi.

Silicide layer 11 defines the electrical characteristics of the Schottky Barrier diode.

At the top of device 8 there is, for example, a metal layer 12, deposited for all the length of device 8. This metal layer 12 is made by aluminum and it acts as an electrode 14, forming the anode.

Epitaxial layer 10 makes a common drain layer for device 8 and, inside said epitaxial layer 10, it also includes a plurality of regions 13, called columns, of an opposite conductivity type.

The p type columns 13 are optimally doped to balance the charge on n type zone 10. When this condition is reached, the electric field upon the

entire volume of the drain region 10 is constant and it is also equal to the critical electric field of the silicon.

This embodiment allows a high voltage to be sustained while maintaining low resistivity in n type zone 10.

As a result of the presence of regions or columns 13, it is possible, therefore, to reduce the resistivity of epitaxial layer 10 without decreasing the breakdown voltage of the Schottky barrier diode 8, because the breakdown voltage depends on the resistivity and on the thickness of the portions of the common drain layer 10 beneath the metal layer 12.

Substantially the presence of doped regions 13 under metal layer 12 allows achievement of the desired breakdown voltage and capability of current transportation even with an epitaxial layer having a lower resistivity than that necessary with respect to conventional Schottky barrier diodes.

To form the doped regions 13 a p - type dopant, such as boron, is implanted.

During the growth of epitaxial layer 10, that involves a thermal process and the p type dopant diffuses vertically into epitaxial layer 10 to form a plurality of bubbles 23 to realize the p type columns 13.

The Multi Drain process of the present invention provides that the p type columns 13 are made by a sequence of successive growths of the n type epitaxial layer 10 and by p type dopant implants. This is possible by means of suitable masks that localize the p type bubbles 23 in n type epitaxial layer 10.

A successive thermal process modifies the p type bubble sequences into the p type columns 13.

The dopant concentration of the p type columns 13, together with their geometrical disposition and size, is suitable to sustain the desired

high voltage.

The dose of these implants ranges, for example, from 1×10^{12} to 5×10^{13} at / cm^2.

As a consequence of the decreased resistivity of the epitaxial layer 10, the on - resistance of the device 8 is reduced, and the current flux coming from the anode electrode and flowing towards the substrate 9 encounters a lower resistance.

However, while in conventional Schottky barrier diodes the resistivity of the epitaxial layer 10 is determined on the basis of the desired breakdown voltage, in the present invention the epitaxial layer 10 has a resistivity which is lower than the necessary to achieve the same desired breakdown voltage.

For example in a device working at 500 V, implemented with traditional technology, a resistivity of about 20 Ohm * cm is used, while with the present invention the resistivity can be less than 5 Ohm * cm.

Therefore the Multi Drain structure of the present invention allows a higher value of breakdown voltage to be attained.

Moreover, to improve the value of the breakdown voltage it is necessary to increase the height of the p type columns 13.

Referring to Figure 2, the semiconductor layer 10 is epitaxially grown over the heavily doped substrate 9, and the thickness of the epitaxial layer 10 depends on the voltage class for which the device is provided.

In this specific embodiment for a Schottky barrier diode operating at about 600 V, the thickness of the metal layer 12 is about few μm, the epitaxial layer 10 can have a thickness of more than 40 μm and a value of doping of about 9×10^{14} cm^{-3} and the substrate 9 can have a value of doping of about 2×10^{19} cm^{-3}.

In Figure 3 a second embodiment of a Multi Drain Schottky barrier diode according to the present invention is shown.

As shown in Figure 3, a part of the elements already described in Figure 2, a plurality of body regions 15, made by the opposite conductivity type of the drain layer, is shown.

In the specific embodiment, the drain layer or epitaxial layers 10 are made by an n - type semiconductor and therefore the plurality of columns 13 is made by a p - type semiconductor. The body regions 15 are made by heavily doped p + - type semiconductor.

Said p + type body regions 15, placed at the top of each p - type column 13, reduce the electric field at the surface and in this way, they reduce the leakage current.

The p + type body regions 15 act as a ring guard of the force lines of the electric field and therefore they do not develop any function of contact between the drain layer and the anode electrode.

In Figure 4A a schematic cross sectional view of the Schottky barrier diode is shown.

In Figure 4A a device 22 is shown that is prior art for the embodiments of the present invention illustrated successively in Figures 4 and 5.

In comparing Figure 4A to Figure 1, that there is a couple 21 of p type wells on the border of the metal layer 4. This metal layer 4 defines the device and limits the leakage current.

In Figure 4 and 5 a top plan view of the first embodiment of Figure 2 and a cross sectional view of the same embodiment of Figure 2 along the line V - V are shown.

Particularly in the top plan view of Figure 4 a single Schottky barrier diode with the Multi Drain structure is shown.

The Multi Drain structure comprises a plurality of p type columns 13 and a p + type ring guard 16. It is also shown an n + type channel stop 17, to prevent the leakage current.

Particularly in the cross sectional view of Figure 5 an oxide passivation layer 18, such as probimide, and the n + channel stop 17 are shown. There is also shown a silicide layer 19, made, for example, of Pt, that allows a device with a lower resistance to be realized. Moreover this silicide layer 19 is combined with a metal layer 20, made, for example, of TiNiAu, that acts as a finish of the wafer slice to improve the current flux.

It is to be noted, as shown in Figures 4 and 5, that the horizontal layout of the device, according to the present invention, is a structure that grows substantially vertically with a well defined number of p type columns, starting from a stripe layout closed around by a sequence of rings of type p. These p type rings of the board extend also vertically as a column shape.